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- Comment on Knutti et al. 2017 paper on model weighting

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Still weighting to break the model democracy

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Abstract Ensembles of climate model simulations are employed to project how climate might change in the future. How do these ensemble projections relate to what will happen to the real-world climate?

The sixth generation is coming. Plans for the Coupled Model Intercomparison Project, Version 6 (CMIP6), are now well formed [*Eyring et al.,* 2016], and the sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6) will be scoped in May 2017. Our thoughts turn, once again, to the thorny problem of how to interpret a collection of climate model experiments [*Knutti et al.*, 2010]. A prominent issue is that of how to take the model projections and produce the best assessment of how the real-world climate would change (given assumptions about future emissions). Should we consider each model projection to be equally valid—the model democracy—or can we bring some of our understanding of how models and the real climate system behave in order to consider an alternative approach?

Reto Knutti and colleagues have returned to this issue in this volume of Geophysical Research Letters [*Knutti et al.,* 2017]. They provide some robust justification about why the "one model one vote" system is flawed. Ensembles such as CMIP6 are not composed of models that are independent, equally plausible, distributed around reality nor representative of "true" uncertainty in projections. All are valid criticisms and also potentially insurmountable problems. Generating an unbiased, independent, and truth-centered ensemble of climate projections, in the absence of large volumes of verification data as can be done in the weather forecasting, seems a tough problem. The only hope, therefore, seems to be in the subselection or reweighting of ensemble members to form projections.

Knutti et al. provide an elegant approach to reweighting that takes into account both the evaluation of the ability of models to simulate present-day climate and their nonindependence. Models that simulate the real world poorly are downweighted, as are models that duplicate other models. They apply the reweighting scheme to projections of Arctic September sea ice and temperature and test the projections using a neat "perfect model" or "perfect ensemble" setup, whereby each model is taken as a realization of the truth and the projections are scored according to some metric. They use the scoring system to justify the values of the free parameters in the weighting scheme. The resulting weighted projects warm more rapidly in the Arctic, and the sea ice extent proceeds at a faster rate, similar to what was concluded in the IPCC Fifth Assessment Report [*Stocker et al.,* 2013].

Have Knutti et al. solved the model democracy problem? This is a step forward but not the final word. They rightly note the critical issue of choosing a weighting diagnostic that is relevant for the projection variable of interest. Sometimes, but rarely, "emergent constraints" are possible in which a direct correlation is found between a measurable variable and a projection variable [*Collins et al.,* 2012]. Even then, care must be taken to consider model drifts, errors common to all models and the harder-to-grasp issue of the physical realism of all models. A long list of recommendations is provided when applying this new technique, including showing weighted and unweighted projections and testing robustness and sensitivity. These recommendations should be followed carefully.

Knutti et al. have picked a problem that has been looked at in the past [*Boe et al.,* 2009; *Bracegirdle and Stephenson*, 2013; *Massonnet et al.,* 2012]. One could argue that they have set themselves up for success by choosing a projection variable in which there are known model errors that are strongly related to the projection variable of interest. Much harder problems present themselves, notably when considering projection variables involving dynamical variations such as storms and more regional climate change [*Shepherd*, 2014; *Xie et al.,* 2015]. Even for a basic but highly policy-relevant climate projection variable such as mean precipitation (Figure 1), there are multiple problems to be overcome. Models have large biases in their simulation of the present day, some of which are common to all models, and there are disagreements between even the

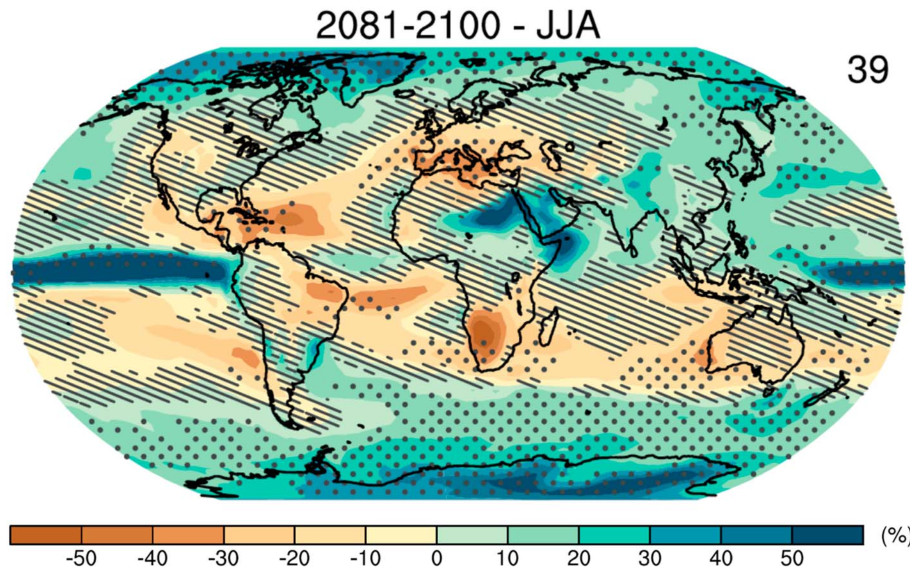

Figure 1. The CMIP5 multimodel mean June–August precipitation change in the period 2081–2100 minus the period 1986–2005 under the RCP8.5 future scenario. Hatching indicates areas where changes are small with respect to natural variability (less than 1 standard deviation), and stippling indicates regions where at least 90% of the 39 CMIP5 models agree on the sign of precipitation change. Figure adapted from *Collins et al.* [2013, Figure 12.22, p. 1078].

sign of the precipitation change. Multiple physical processes contribute to the changes, including coupling with the ocean and dynamical processes in the atmosphere associated with, e.g., monsoons. Hence, simple emergent constraints have not, yet, been found.

The Knutti et al. study provides a useful step forward in the use of climate model ensembles to assess projections of climate change in the real world, but it is not the final word. While we work hard to improve models, we also have to work hard to understand how to interpret their projections.

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